REMARKS

Claims 1-10, 13-33, 36-45, and 93-106 are pending. New claims 99 and 100 are supported by, for example, originally filed claim 22. New claims 101, 102, 105, and 106 are supported by, for example, Figs. 4, 5A, 5B and accompanying text. New claims 103 and 104 are supported by, for example, originally filed claim 45.

Claims 1-3, 6-23, 25-28, 32, 33, 36-46, 93, 94, 96, and 97 are rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos et al., U.S. Patent No. 5,955,749 (hereinafter "Joannopoulos") in view of Imada et al, *Coherent two-dimensional lasing action in surface-emitting laser with triangular-lattice photonic crystal structure*, 75 Applied Physics Letter 316 (1999) (hereinafter "Imada") and Vaudo et al., U.S. Patent 6,156,581 (hereinafter "Vaudo"). Applicants respectfully traverse the rejection.

Claims 1 and 25

Claim 1 recites "a second semiconductor layer doped with a second dopant, . . . a second electrode layer on said second semiconductor layer; and a periodically-arranged plurality of holes formed in the second semiconductor layer and extending towards the first semiconductor layer." Claim 25 is amended to include similar elements. Claims 1 and 25 therefore teach a device with an electrode on a layer with a plurality of holes.

A. Neither Imada nor Joannopoulos teach forming electrodes on a layer with a plurality of holes

As Applicants noted in the office action response mailed April 4, 2003, in contrast to the devices in claims 1 and 25, in Imada's device, the n-InP clad layer with a triangular lattice structure is sandwiched between planar semiconductor layers. The electrodes are formed on planar semiconductor layers, not on layers with a plurality of holes. See Imada's

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FIG. 1(a). As noted by the Examiner in paragraph 10 of the office action, Joannopoulos does not teach any electrode structure. Thus, even in combination, Joannopoulos and Imada do not teach all the elements of claim 1. In addition, neither reference teaches or suggests modifying Imada's electrodes for use on a layer with a plurality of holes, and neither reference teaches or suggests how Imada's electrodes could be modified for use on a layer with a plurality of holes. Accordingly, claims 1 and 25 are patentable over the combination of Joannopoulos and Imada.

Vaudo is cited only as teaching a GaN based light emitting diode and contains no mention of a photonic crystal or plurality of holes. As such, Vaudo adds nothing to the deficiencies of Joannopoulos and Imada.

B. The formation of electrodes on a layer with a plurality of holes is not trivial

In response to the above argument that neither Joannopoulos nor Imada teaches forming an electrode on a layer with a plurality of holes, the Examiner states, in paragraph 28 on page 5 of the present office action:

> Applicant states that Joannopoulos et al. do not show an electrode but note that since an improvement in an LED structure is described, an electrode structure is a necessity and is obvious but note that Imada et al. specifically show an electrode and its incorporation is obvious.

The Examiner's argument ignores the fact that extensive modification of Joannopoulos and Imada would be required to result in the device in claims 1 and 25. As described above, neither reference supplies a motivation for or an expectation of the success of such a modification.

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In addition, Applicants clearly state in the background section of the present application that such modification of Joannopoulos and Imada is not obvious. For example, Applicants note in the background section that the formation of electrodes on a photonic

crystal LED may affect the extraction of light from the device. In addition, the formation of electrodes on photonic crystal LEDs may require fabrication techniques not used with regular LEDs. See for example, paragraph [0008] which states:

> The fabrication of electrodes in regular LEDs is known in the art. However, for PXLEDs, neither the fabrication of electrodes, nor their influence on the operation of the PXLED is obvious. For example, suitably aligning the mask of the electrode layer with the lattice of holes may require new fabrication techniques. Also, electrodes are typically thought to reduce the extraction efficiency as they reflect a portion of the emitted photons back into the LED, and absorb another portion of the emitted light. (Emphasis Added)

See also, for example, paragraph [0011] which discusses an article by R.K. Lee et al.:

> The addition of the electrodes [to Lee et al.'s device], however, will substantially affect the extraction and the spontaneous emission. Since this effect is unknown, it cannot be disregarded in the design of a[n] LED. Since the Lee et al. design does not include such electrodes, the overall characteristics of an LED, formed from that design, are unclear. (Emphasis Added).

The above quoted paragraphs illustrate that the addition of electrodes to a photonic crystal device is not trivial. Accordingly, lacking any motivation in either Joannopoulos or Imada, it cannot be obvious to modify the combination of Joannopoulos and Imada to result in the electrode structure claimed in claims 1 and 25.

C. Imada's electrodes are not suitable for a light emitting diode

In paragraph [0068], Applicants note "some embodiments emit most of the generated light through host substrate 102, while other embodiments emit most of the light through the side opposite to host substrate 102, sometimes referred to as the top of the LED." Such arrangements, where light is extracted either through the substrate or through the top of the epitaxial region, are typical for LEDs. In contrast to claims 1 and 25, which recite "light emitting diodes," Imada teaches a "surface-emitting laser." Imada does not specify how light is extracted from the device, but Imada's Fig. 3(a) shows that in Imada's device, light

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from the top surface is almost completely absorbed by the electrode shown in Fig. 1(a). Though Imada does not specifically show a second electrode, the images in Fig. 3(a) which show near field images of light from the top of Imada's device, suggest that Imada's second electrode is an opaque sheet electrode formed on the bottom of the structure in Fig. 1(a) labeled "n-InP SUB." Accordingly, a significant portion of the top surface and all of the bottom surface of Imada are opaque to light. Such an arrangement of electrodes is completely unsuitable for a light emitting diode, where light is extracted through the top or bottom surface of the device. Since there can be no motivation to use an electrode arrangement that renders opaque each of the possible light extraction surfaces of the light emitting diode, there is no motivation to use the arrangement of electrodes taught by Imada in a light emitting diode as claimed in claims 1 and 25.

D. Conclusion

The combination of Joannopoulos, Imada, and Vaudo fail to teach an electrode on a layer with a plurality of holes and thus fail to teach every element of claims 1 and 25. As Applicants noted in the background section, the design of electrodes in a photonic crystal device is not trivial. In addition, a person of skill in the art would not consider the electrode structure of Imada to be suitable for a light emitting diode, since Imada's electrodes render opaque the surfaces from which light is typically extracted in a light emitting diode. Accordingly, the Examiner has failed to point to a motivation to make the significant modifications to the combination of Joannopoulos, Imada, and Vaudo required to form the device of claims 1 and 25. The Examiner has thus failed to make a prima facie case of the obviousness of claims 1 and 25. Applicants respectfully submit that claims 1 and 25 are allowable over the combination of Joannopoulos, Imada, and Vaudo.

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Claims 6 and 27

Claims 6 and 27 recite "a surface in one of the plurality of holes has a surface recombination velocity less than 10^5 cm/sec."

Claims 6 and 27 depend from claims 1 and 25 and are therefore allowable for at least the reasons stated above for claims 1 and 25. In addition, as Applicants noted in the Office Action response mailed April 4, 2003, the Examiner states in the office action that "the surface recombination velocity is inherent in the structure." Applicants respectfully submit that the surface recombination velocity is not inherent in the structure, and can be influenced by the manner in which the holes are formed. For example, some fabrication techniques can damage the crystal layer or layers in which the holes are formed, which may increase the surface recombination velocity in a device.

In response to the above arguments, the Examiner stated in paragraph 29 of the office action, "Regarding the inherency of the surface recombination velocity, see the combination of the basic references with Vaudo et al." Applicants are unsure what is meant by this comment, since Applicants can find no mention in Vaudo et al. of surface recombination velocity.

In addition, Applicants note Boroditsky et al., *Surface recombination measurements on III-V candidate materials for nanostructure light-emitting diodes*, 87 Journal of Applied Physics, Volumn 87, Number 7, pp. 3497-3504, 3500 (2000), cited in the accompanying information disclosure statement. Boroditsky et al. state:

> In our experiment, the PL of an 'as-grown' GaN sample was first measured to determine the internal quantum efficiency and the surface recombination velocity (SRV), which was found to be $S = 2.8 \times 10^4$ cm/s. The same was then etched in a chemically assisted ion beam etching machine for 1 min in $Ar^+ + Cl_2$, which removed 30 nm from the top cap layer. Figure 3 shows that after etching, . . . SRV increased to $S = 7 \times 10^4$ cm/s.

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The above-quoted passage clearly demonstrates that the surface recombination velocity is not inherent to a device, since the same material may have two different surface recombination velocities, depending on how the material was etched.

Though Boroditsky et al. teach surface recombination velocities less than 10^5 cm/sec, Boroditsky et al. is only etching the surface of a c-plane layer of III-nitride crystal. In contrast, forming a plurality of holes necessarily exposes crystal surfaces other than the c-plane. Accordingly, a person of skill in the art would expect that the SRV values given in Boroditsky et al. would have no bearing on the surface recombination velocity of a surface in one of the plurality of holes as recited in claims 6 and 27.

Since a surface recombination velocity less than 10^5 cm/sec is not inherent in the structures taught by Joannopoulos, Imada, and Vaudo, claims 6 and 27 are allowable for this additional reason.

<u>Claims 2, 3, 7-23, 26, 28, 32, 33, 36-46, 93, 94, 96, and 97</u>

Claims 2, 3, 7-23, 26, 28, 32, 33, 36-46, 93, 94, 96, and 97 depend from claims 1 and 25 and are therefore allowable for at least the reasons stated above for claims 1 and 25.

<u>Claims 4, 5, and 29-31</u>

Claims 4, 5, and 29-31 are rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos in view of Imada, Vaudo and further in view of Kurahashi. Claims 4 and 5 depend from claim 1. Claims 29-31 depend from claim 25. Kurahashi adds nothing to the deficiencies of Joannopoulos, Imada, and Vaudo with respect to claims 1 and 25, accordingly claims 4, 5, and 29-31 are allowable for at least the same reasons as claims 1 and 25.

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Claim 24

Claim 24 is rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos in view of Imada and further in view of Roberts et al., U.S. Patent No. 6,335,548. Claim 24 depends from claim 1. Roberts et al. add nothing to the deficiencies of Joannopoulos and Imada with respect to claim 1. Accordingly, claim 24 is allowable for at least the same reason as claim 1.

Claims 95 and 98

Claims 95 and 98 are rejected under 35 U.S.C. 103(a) as being unpatentable over Joannopoulos in view of Imada, Vaudo, and further in view of Dodabalapur et al., U.S. Patent No. 6,363,096. Claims 95 and 98 depend from claims 1 and 25. Dodabalapur et al. is cited as teaching "a one-dimensional photonic crystal" and as such adds nothing to the deficiencies of Joannopoulos, Imada, and Vaudo with respect to claims 1 and 25. Claims 95 and 98 are therefore allowable for at least the same reasons as claims 1 and 25.

In addition, Dodabalapur et al. teaches a grating "fabricated by nanomolding a resonator structure and applying a film of Alq doped with about 0.5 to 5.0 weight percent of the laser dye DCMIII to the resonator." Col. 5, lines 25-28. Dodabalapur et al. teaches "plastic" lasers (see title) and does not teach or suggest that any of its teachings may be applied to semiconductor LEDs. In fact, Dodabalapur et al. teaches in col. 5, lines 50-52 that the invention of Dodabalapur et al. presents "an advantage over inorganic semiconductor lasers," effectively teaching away from the use of Dodabalapur et al.'s grating in a semiconductor LED device. Accordingly, Dodabalapur et al. cannot be properly combined with Joannopoulos, Imada, and Vaudo and claims 95 and 98 are allowable for this additional reason.

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In view of the above arguments, Applicants respectfully request allowance of all pending claims. Should the Examiner have any questions, the Examiner is invited to call the undersigned at (408) 382-0480.

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Respectfully submitted,

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